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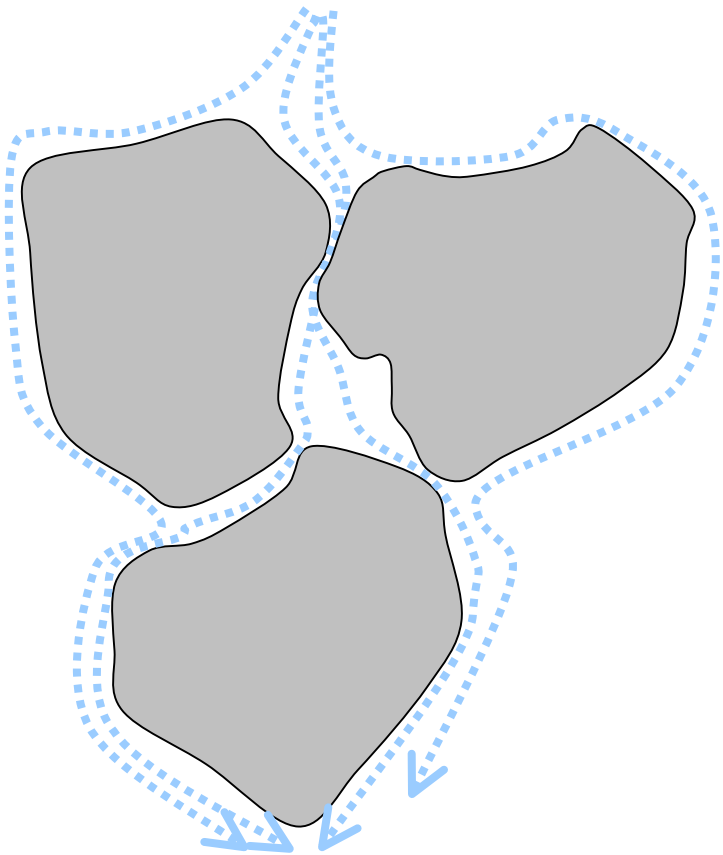
A New Paradigm for Pathogen Transport and Deposition in Porous Media: The Role of Pore Structure and Colloid-Colloid Interactions



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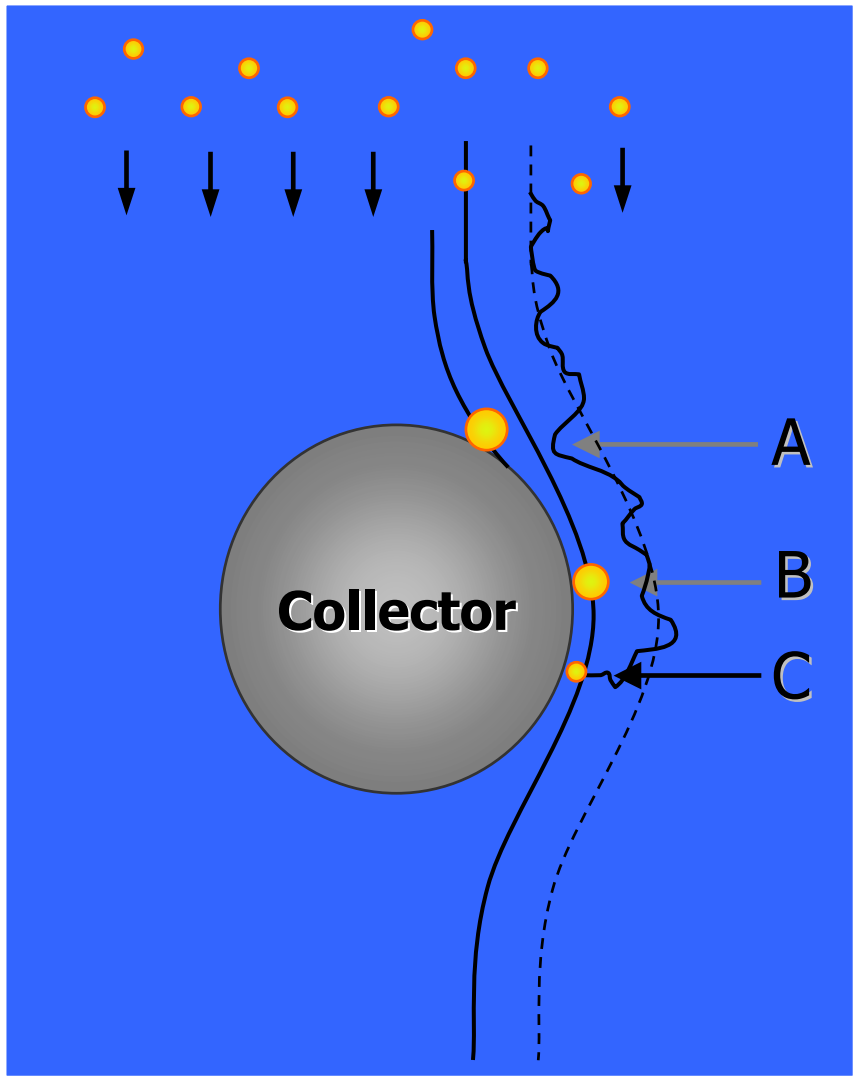
Presented at the CSREES
National Water Conference

Filtration Theory

- Deposition of colloids occurs at the solid-water interface
- Mass transfer occurs via sedimentation (A), and interception (B), and diffusion (C)
- Retention controlled by DLVO interactions and force/torque balance

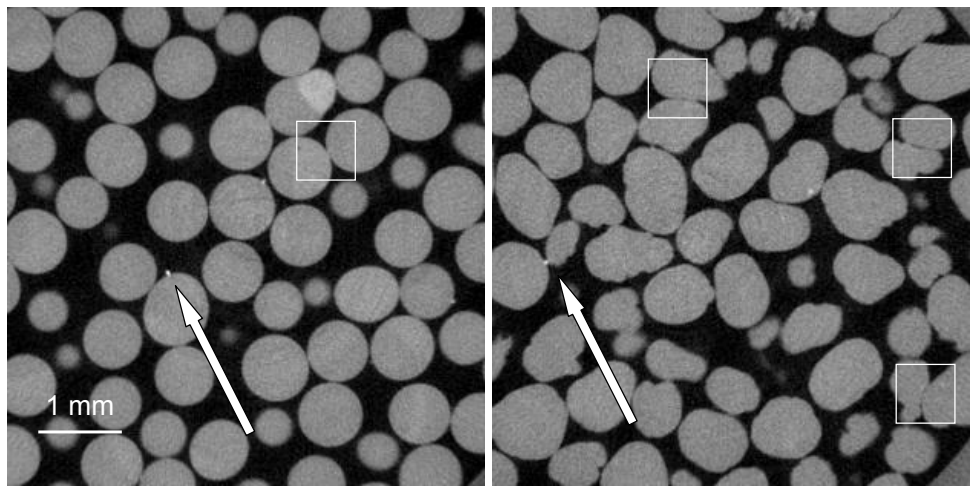


Gaps in Knowledge

- Absence of an energy barrier:
  - Conc. of deposited colloids decrease exponentially with distance
  - Predicted well by clean-bed filtration theory
- Presence of an energy barrier:
  - The spatial distribution of deposited colloids is drastically different; non-exponential
  - Non-exponential deposition pattern especially true for larger colloids and finer texture porous media
- Proposed reasons for current model's shortcomings:
  - Role of pore structure
  - Role of colloid-colloid interactions
  - Role of secondary energy minima and fluid drag

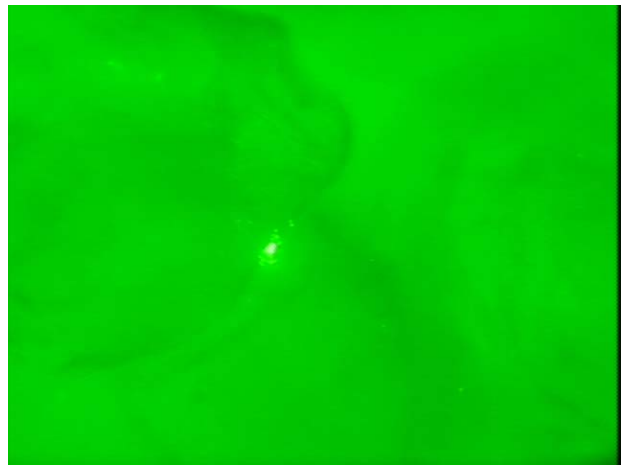
Evidence Suggesting Role of Pore Structure

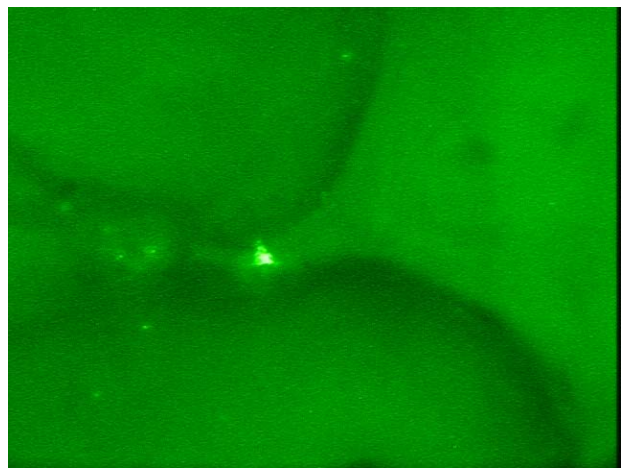
- Role of Pore Structure
  - Model developed for a *single spherical grain collector*.
  - Theory neglects pore structure and grain-grain junctions, with only indirect accounting for porosity with Happel correction factor
  - The spatial relationship of the colloids determined using cross-sectional XMT images (20 μm resolution) of porous media by stepping through image planes above and below to establish the environment of deposition (Li et al., 2006).



Evidence Suggesting Colloid-Colloid Interactions

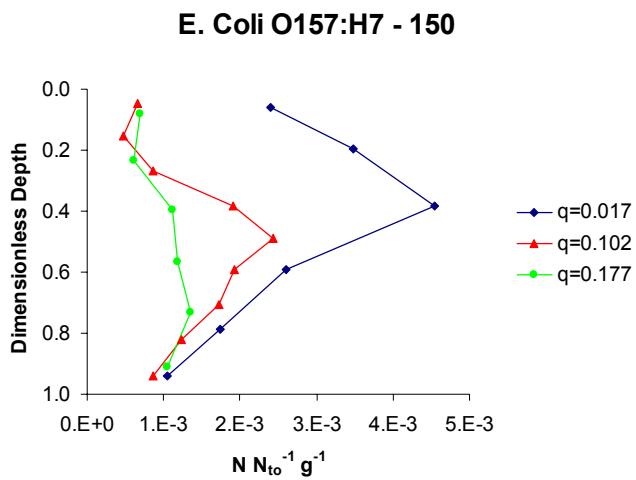
- Time dependent deposition:
  - Clean porous media vs. media already containing deposited colloids
  - Enhanced deposition *may occur*
    - Deposited particles serve as favorable sites for subsequent colloid attachment (ripening)
    - As a result of plugging of pore spaces
- Pore domain geometry contributes to the process of colloid-colloid aggregation
- Colloid-colloid interactions may be an important deposition process even under “clean bed” conditions.



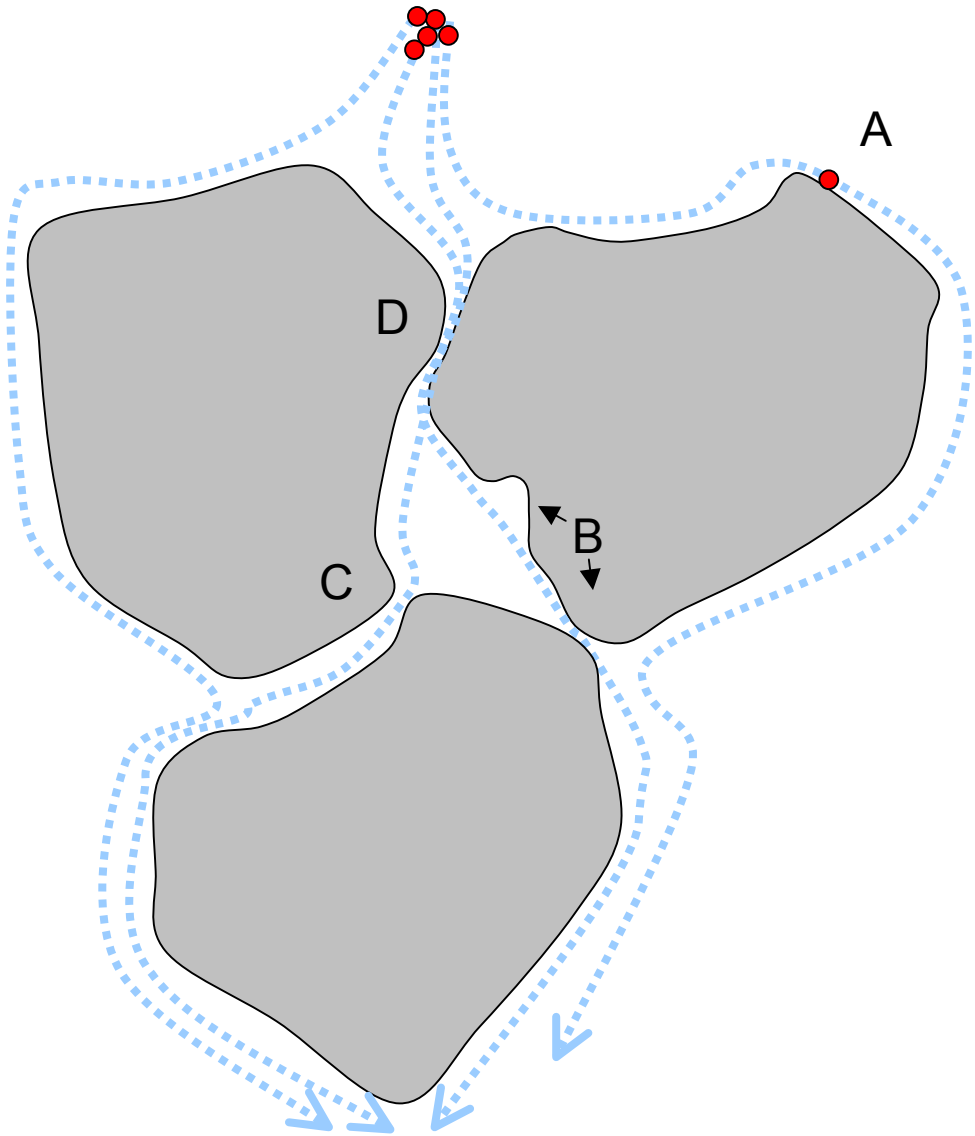


Evidence Suggesting Role of Secondary Energy Minima Interactions and Fluid Drag

- 2° minima colloid association with grain surfaces
  - Subject to fluid drag; translation of the colloid along grain surface
  - Retention requires zones of flow stagnation or physical constriction
- Evidence of colloid (and aggregate) mobilization
  - Retained colloid profiles deviate from the log-linear behavior expected from existing filtration theory
  - Profiles vary non-monotonically with transport distance and exhibit peak at some distance down-gradient from the source



Presence of Energy Barrier



<u>Types of deposition occurring:</u>

A. Primary minima deposition at point of contact (heterogeneity)

B. Deposition within secondary minima
   - Translation along grain into a stagnant region or a pore constriction

C. Removal due to pore structure/grain-grain contacts

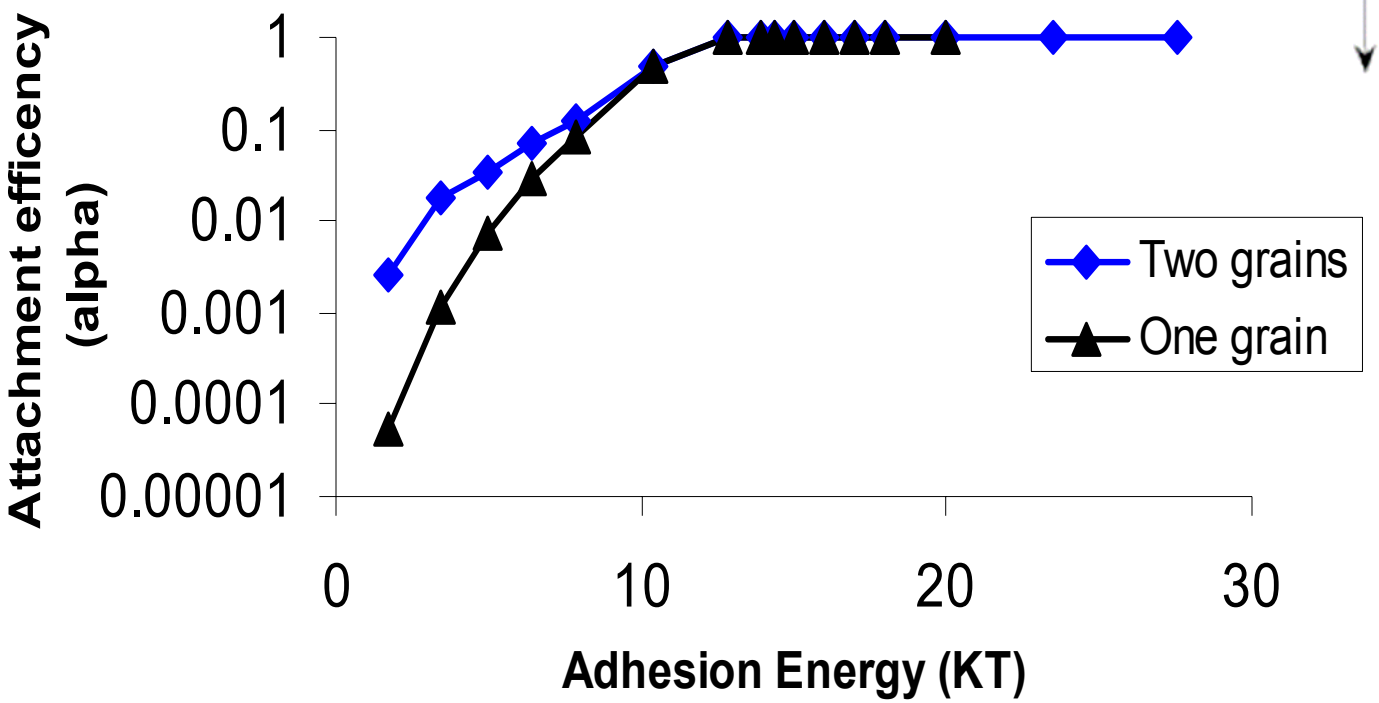
D. Pore structure influencing colloid-colloid interactions

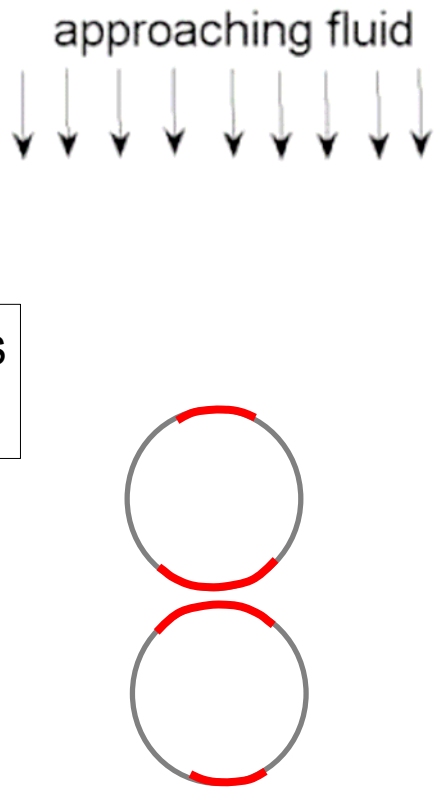
Research Approach

- Pathogen Characterization:
- Forces:
  - DLVO calculations
  - AFM measurements
- Micromodels:
  - Impinging Jet
  - Parallel flow
- Batch and Column Experiments:
- Mathematical Models:
  - Pore scale
  - Continuum
  - Stochastic

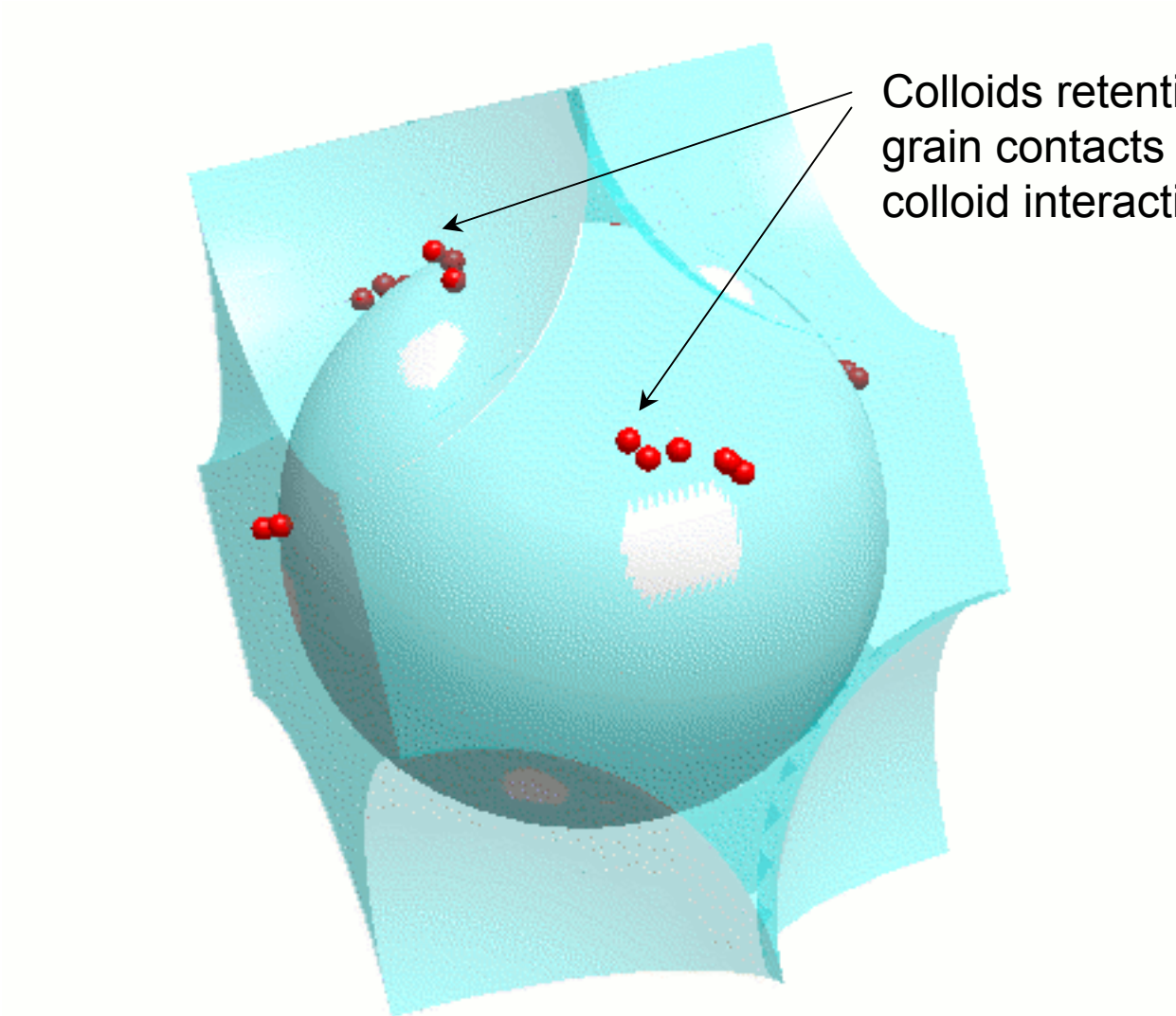
Attachment Efficiency vs Adhesion Energy

(v=5x10^{-5} m/sec)





Evidence of Retention in Pore Structure



Colloids retention at grain-grain contacts with colloid-colloid interactions.

Conclusions

- Results indicate a strong coupling between physical (pore geometry, colloid size, and hydrodynamics) and chemical (solid and solution chemistry) factors on colloid transport and retention.

Ongoing Work

- Colloid and pathogen (*E. coli* O157:H7, *Cryptosporidium*) experiments in packed bed
- Colloid experiments in impinging jet and parallel plate
- Pore-scale modeling – single collector, ensemble of collectors, colloid-colloid interactions
- Continuum and stochastic modeling